First Radiometric Validation of AIRS on the EOS using the 20 July 2002 Focus Day Data*

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ABSTRACT

The Atmospheric Infrared Sounder (AIRS) on the EOS Aqua spacecraft is an infrared spectrometer/radiometer which covers the 650 – 2700 cm^{-1} region of the spectrum with 2378 spectral channels. The EOS Aqua was launched on 4 May 2002 from Vandenburg AFB, California, into a 705km high, sun synchronous orbit. First tests of the radiometric calibration using the analysis of (observed – calculated) for data from a single, relatively cloud free 2500 x 2500 km area of the subtropical Atlantic ocean confirm absolute radiometric accuracy of better than 0.5K. The spectral information in the data also suggests that the analyzed region contained more moisture than the NCEP analysis.

1. INTRODUCTION

The Atmospheric Infrared Temperature sounder (AIRS) was launched on 4 May 2002, on the EOS Aqua satellite. The AIRS objective is to provide sounding data for operational numerical weather forecasting and radiometrically calibrated spectra in support of NASA's climate and process research. AIRS is a grating array spectrometer which covers the spectral range from 650 to 2700 cm^{-1} (3.7 to 15.4 microns) with 2378 spectral channels and spectral resolution $\Delta\lambda/\lambda$=1200. In order to optimize the performance as a radiometer, the spectrometer optical elements are passively cooled to 150K, with active control at the 0.01K level. Detector performance is optimized by cooling the detectors with a Sterling type refrigerator to 58K. Background information on AIRS are given by Aumann et al. (2003).

For the purpose of radiometric calibration the AIRS spectrometer is a simple cross-track scanning radiometer with 2378 spectral channels. Each scan line consists of 90 scene footprints (1.1 degree, corresponding to a 13.5 km diameter at nadir), a calibration using a full aperture wedge blackbody calibration source set to 308K (the OBC), and four cold space views (SV) for every scan line. Each scan line repeats ever 2.667 seconds. During the scan line the spacecraft moved one footprint diameter forward in the orbit. A radiometrically calibrated map of the ground is thus obtained at the 2378 frequencies. The gain of each of the 2378 AIRS channels is independently determined and the noise of the detectors is uncorrelated. The radiometric correlation due to the common use of the OBC and the use of the same cold space views for the entire scan line is inherent to this design. By including a number of second order terms, such linearity correction, scan mirror temperature and scan angle dependent polarization effects, the quality of the absolute radiometric calibration can be improved to reach laboratory standards. An extensive pre-launch calibration effort using a NIST traceable blackbody demonstrated absolute radiometric calibration accuracy at the better than 0.2K level for scene temperatures between 215K and 315K (Pagano et al. 2000). This excellent performance is made possible by the fact that the AIRS spectrometer is cooled to 150K, i.e. well below the coldest temperature expected to be measured in the Earth scene. The better than 0.2K radiometric calibration is matched by low instrument noise, measured as Noise Equivalent Delta Temperature (NEDT), which is of the order or 0.2K or less for most AIRS channels for each footprint. The AIRS radiometric calibration algorithm is described in the AIRS Calibration Theoretical Basis Document (ATBD) (Aumann et al. 2000). In the following we discuss the first verification of the AIRS radiometric calibration using a single, reasonably cloud-free night granule of data from the 20 July 2002 focus day. One granule covers an area of about 2500 x 2500 km with 12150 footprints in 135 scan lines, and corresponds to six minutes of data.

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2. APPROACH

The evaluation of the radiometric accuracy proceeds in two steps:

1. Identify footprints which are free of clouds, without assuming the validity of the absolute calibration.
2. Use the sea surface temperature from a model to establish radiometric performance in reasonably transparent areas of the spectrum by analyzing (observed – calculated).

For the identification of footprints which are free of clouds over water we reject pixels where the land fraction, calculated for each pixel based on the known scan angle and spacecraft position, exceeded 1%. We then use a spatial coherence test (SCT) which makes two assumptions: 1. We assume that any footprint where the brightness temperature measured in a good atmospheric window is lower that 280K, can be rejected. 2. We assume that at night the tropical and subtropical ocean temperatures are uniform at the measurement noise level and on a 45 km scale, i.e. in the absence of clouds the brightness temperature measured by a good surface channel and its eight surrounding pixels, which cover a 45 km spot on the ground, should agree within the noise. Any low noise surface channel will do for this test. We selected the 2616 cm^{-1} super window channel. Since its NEDT=0.1K at 300K, 90% of the measurements of adjacent footprints should agree within 0.25K for a uniform scene. Other than the 280K rejection threshold the SCT makes no assumptions about the validity of the absolute calibration, but the data analysis assumes that a reasonable fraction of the footprints is clear. We make sure that the “reasonably clear” assumption is satisfied by sampling each granule with the SCT and by selecting only those granule which are more than 50% ocean with at least 500 “ SCT clear” pixels.

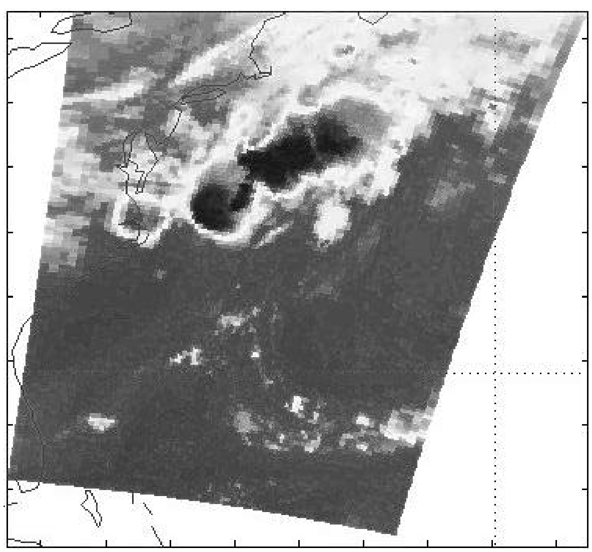

Figure 1. Brightness temperature image of granule 2002.07.20.066 at 900 cm-1. The white. light gray and black areas are clouds. For clear ocean see Figure 2.

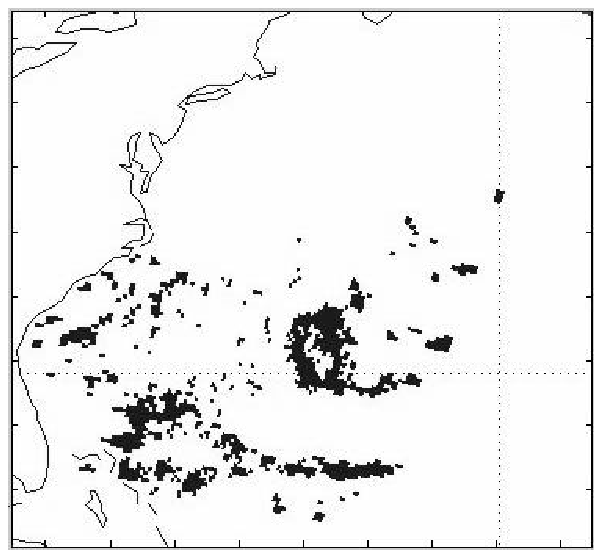

Figure 2. Cloud mask using the spatial coherence test with 0.5K threshold. Of the 9676 ocean pixels, 860 are clear. The black areas are clear, ocean and T>280K.

3. RESULTS

Figure 1. shows the brightness temperature at 900 cm^{-1} of granule 2002.07.20.066 with the coastline map overlaid. This granule covers a large part of the Atlantic Ocean north of Cuba and east of Florida. Figure 2. shows a map of the pixels identified by the SCT as ocean and clear using a spatial coherence test with the 0.5K threshold.

Of the 12150 pixels in the granule, 9676 were identified as ocean with T>280K. Using SCT thresholds of 0.25K, 0.5K and 0.75K, which identify 164 , 860 and 1670 clear pixels at a median skin temperature of 299.63, 299.51, and 299.36, respectively, yields an estimate of residual cloud contamination. Since extrapolating to zero suggests that 299.7K is clear, SCT(0.25K) and SCT(0.5K) may have about -0.1K and –0.2K of cloud contamination. It is interesting to note that the yield of "cloud-free" pixels at the 0.2K level, i.e. near the AIRS random noise, is very low for the clearest night ocean granule of 20 July 2002. For SCT(0.25K) and SCT(0.5K) only 1.5% and 9%, respectively, are reasonably clear. In the following we use SCT(0.5K) for the statistical evaluation, realizing that it potentially is cold biased by 0.2K.

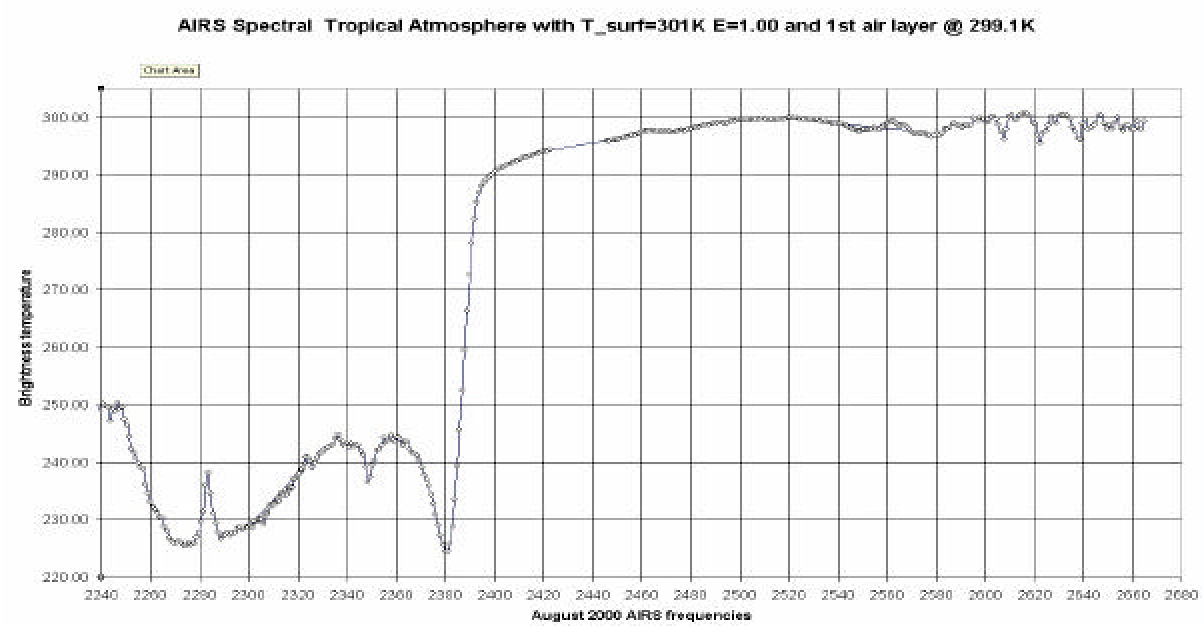

Figure 3. Typical calculated spectrum for a cloud-free tropical atmosphere.

Bias spectra: The evaluation (observed – calculated) at night under cloud free conditions produces bias spectra. For those footprints identified as clear by the SCT we evaluate the statistics of (bt(ν) – sbt(ν).ncep), where bt(ν) is the brightness temperature measure by AIRS at frequency ν, and sbt(ν).ncep is the top-of-atmosphere (TOA) corrected brightness temperature at frequency ν calculated based on T(p), q(p) and the SST in the NCEP model. The procedure for calculating the AIRS radiances is described by Fishbein (2003). It uses the radiative transfer algorithm (RTA) developed by Strow (2003) and the T(p), q(p) from the NCEP analysis grid, interpolated to the AIRS footprint positions. In the following we focus on bias spectra from the more transparent portions of the atmosphere in the 2500 and 900 cm^{-1} regions of the spectrum.

Figure 3. shows a calculated spectrum of sbt(ν).ncep between 2240 and 2690 cm^{-1} . The bias spectrum of (bt(nu)-sbt(nu).ncep) for pixels identified as "clear" is shown in Figure 4. Dotted lines going vertically off scale are bad channels. The calculations are carried out in radiance units, and the difference radiance is converted to the equivalent temperature difference for a scene at a temperature of 300K. All data fit between ± 1, with the majority between ± 0.5K. What appear to be random scatter are, on closer inspection, highly correlated deviations which correlate with water and CO_2 spectral features.

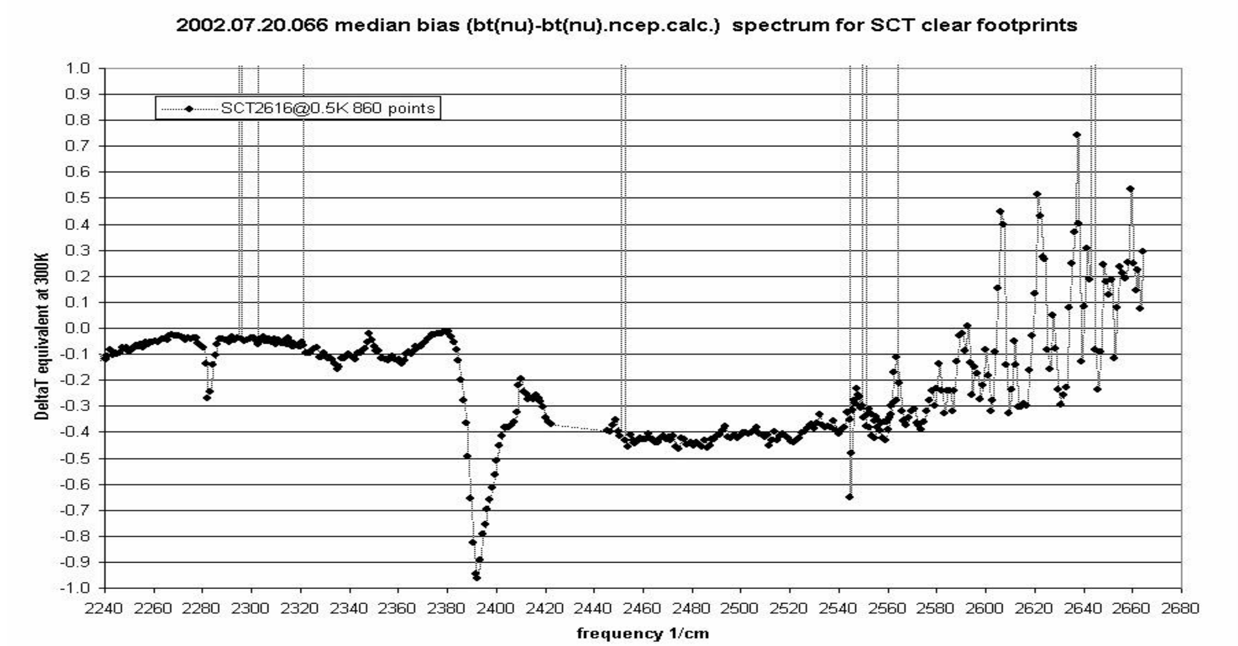

Figure 4. Observed bias spectrum for the cloud free pixels of granule 133 of 20 July 2002 shows that the bias in the highly transparent regions of the 2240-2680 cm-1 region of the spectrum is less than 0.4K

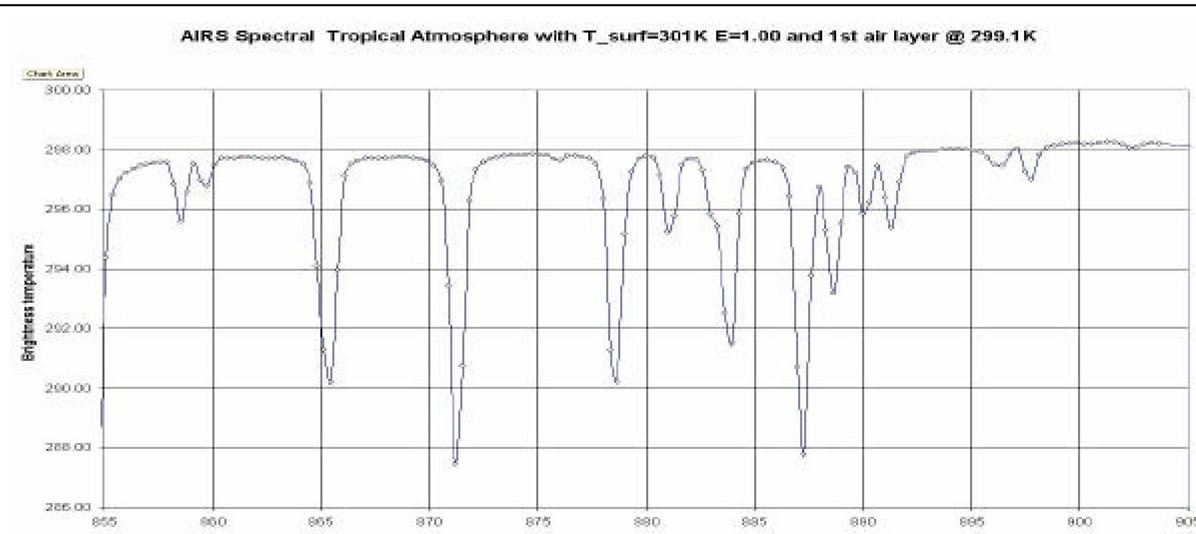

Figure 5. Calculated brightness temperature spectrum between 855 and 905 cm-1.

The most obvious spectral feature in Figure 4. near 2390 cm^{-1} is not related to calibration, but is due to the use of incorrect R-branch calculations in the pre-launch RTA. This is discussed by Strow et al. (2002). In the 2240 through 2380 cm^{-1} region, where the temperature ranges from 220K to 250K because the channels never see the surface, the bias is less than 0.1K. This can only be interpreted as meaning that the calibration in this region is excellent, the transmission of CO_2 is well understood, and the temperature profile in the NCEP model is very accurate. In the highly transmitting region between 2440 and 2680 cm-1 there is a bias between –0.4 and –0.3K, except in the water lines, i.e. the observed is colder than expected (calculated). Since the NCEP SST is tied to the temperature of the buoys (at about 6 meter depth), while AIRS measures the skin temperature in the upper few microns of the water surface, a small cold bias would be expected. The mean difference between ATSR SST_{skin} and TOA corrected SST_{buoy} at night and wind speed > 6 m/sec is -0.17+/- 0.46K (Donlon et al. 2002), with values as low as -0.6K at lower wind speeds. The determination of absolute calibration for non-global data using the SST is thus limited by the uncertainty in the (skin – buoy) correction, in addition the regional 0.5K SST model accuracy. Both uncertainties are due to differences in regional conditions of sea state and evaporation from the surface, which average out in global calculations.

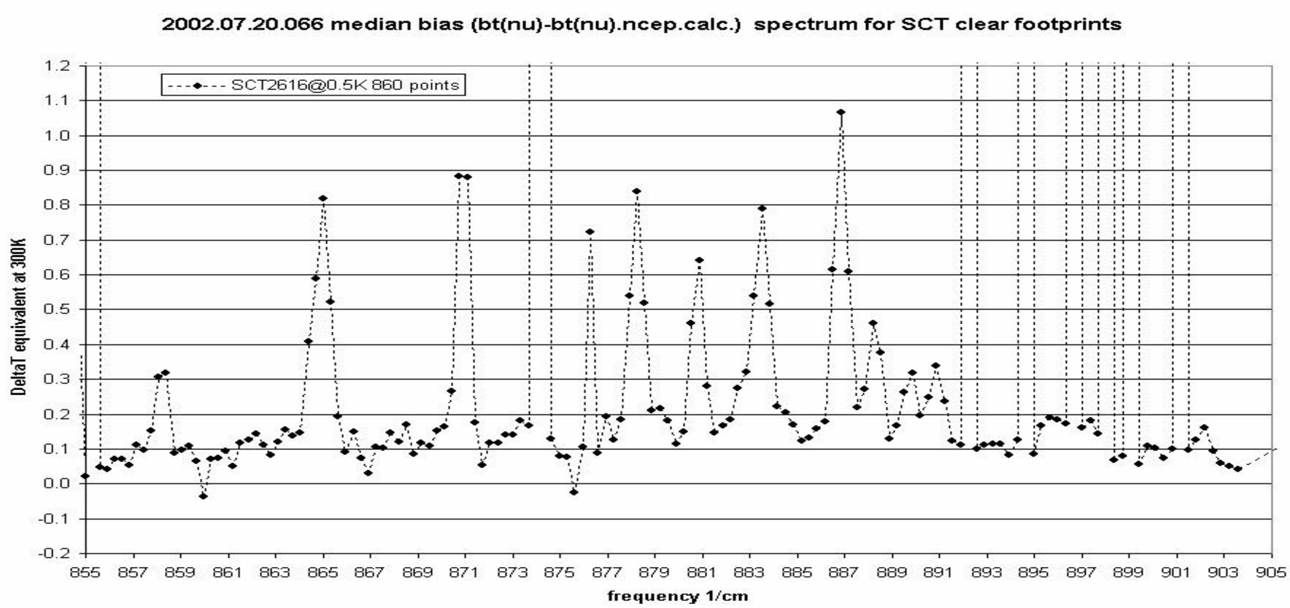

Figure 6. Observed bias spectrum for cloud free pixels

Figure 5. shows a calculated spectrum of sbt(ν).ncep between 855 and 905 cm^{-1} . The bias spectrum of (bt(ν)-sbt(ν).ncep) for pixels identified as "clear" is shown in Figure 6. For the moment we will ignore the interesting bias spectrum which mimics the structure of the water lines shown in Figure 5 and focus on the bias between the lines. The bias in this region is typically +0.1K. This is inconsistent with what we saw in Figure 4. Since the change in water emissivity between 2500 and 900 cm-1 is already included in the calculated radiances, we would have expected the bias in the two spectral regions to be the same. Instead we find a bias of 0.4K between the 2616 and 900 cm-1 window channels. Given the excellent agreement between observed and calculated in the 2240 through 2380 cm^{-1} region, this difference is significant. If we postulate that the AIRS calibration is correct at other frequencies as well, we have three potential explanations for the 0.4K bias: 1. Residual cloud contamination. 2. The TOA correction at 2616cm-1 is incorrect, and/or 3. the TOA correction at 900 cm-1 is incorrect. There may well be residual cloud contamination at the 0.2K level due to the SCT(0.5K), but it would make both spectral regions look colder. Regarding explanation 2) we note that the TOA correction at 2616cm-1 is very small. It can be expressed as bt.toa = sst.ncep – 0.7 – 0.2/cos(theta), where theta is the local slant path angle and the 0.8K adjusts for the emissivity of the ocean with 0.2K uncertainty (Masuda et al. 1988 and VanDelst and Wu 2000). At 900 cm-1 the emissivity of the ocean is 0.99 under almost any conditions. Half the observed difference between 900 and 2616 cm^{-1} could be due to emissivity uncertainty at 2616cm^{-1}. Suggestion 3. is

the most likely. The correction for water vapor absorption in the most transparent channel in this region, 900 cm^{-1}, is about 3K at nadir for tropical ocean climatology. A 10% error in the amount of water vapor in the model for the clear footprints would thus introduce a 0.3K shift in the expected temperature, which would account for almost the entire observed difference. There is direct evidence for possibility 3) in the form of the large bias in the water lines. At the center of the lines the observed temperature is considerably warmer than the calculated temperature, suggesting that either there is about 10% too much water in the average NCEP analysis for the clear pixels in this particular data granule, or that the transmission due to water vapor is overcorrected by 0.4K.

4. CONCLUSIONS

Based on the analysis of a single, relatively cloud free 2500 x 2500 km granule of AIRS data taken on 20 July 2002, we conclude that the absolute radiometry in reasonably transparent parts of the AIRS spectrum is within 0.5K of the NCEP analysis, but could be considerably more accurate. Validation of the calibration approaching the 0.2K accuracy claimed based on pre-launch calibration is complicated by the effects of residual cloud contamination, uncertainty in the surface temperature, surface emissivity and TOA correction. Residual cloud contamination can be reduced to the 0.1K level using the SCT(0.25K), but the yield of "cloud-free" pixels is very low. Assuming that the SST model and water vapor column model data are globally unbiased, the buoy temperature and the water vapor column uncertainty in the TOA correction should average out on a global basis. On a global basis the absolute calibration is thus limited to the accuracy of the assumed (bulk-skin) bias and a frequency dependent bias in the emissivity.

5. ACKNOWLEDGEMENTS

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